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ALL SEASON PETROLEUM HYDRAULIC FLUID FOR GROUND EQUIPMENT

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All Season Petroleum Hydraulic Fluid for Ground Equipment

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A low viscosity petroleum base hydraulic fluid having anti-wear, rust protection and oxidation stability characteristics, has been developed for the gun and turret control system of the M48A2 and M60 tanks. The fluid has a viscosity of 1.32 centistokes at 98.9 C and 381 centistokes at −53.9 C, (low temperature viscosity was dictated by low temperature starting requirements) thereby permitting operation within minutes at −53.9 C, and satisfactory performance at bulk fluid temperatures of approximately 98.9 C. Performance at the latter temperature is comparable to that obtained with currently specified MIL-H-6083B hydraulic fluids.

After a test of 213 hours, wear, leakage and corrosion were negligible or non-existent and no significant changes in fluid properties were noted.

This fluid eliminates the need for hardware modifications (installation of heaters) in order to permit usage at low temperatures of the more viscous MIL-H-6083B specification fluids or alternatively the costly option of using and stockpiling more than one fluid (different viscosities) in order to achieve all weather capability.

INTRODUCTION

Hydraulic fluid, petroleum base, preservative, meeting Specification MIL-H-6083B (modified to MIL-H-6083C in October 1967) is currently used for ground equipment by the U. S. Army as an operational and preservative fluid. In recent performance tests on M48A2 and M60 tanks (both tanks use the same hydraulic gun control system) it was found (*1*) that the gun elevating and turret traversing systems (Fig. 1) would not function at −53.9 C using MIL-H-6083B hydraulic fluid. Since movement of the turret and gun are dependent on the amount of fluid delivered to the hydraulic motor and to the elevating mechanism respectively (Fig. 1), it becomes apparent that the principal cause of inoperability is the fact that the hydraulic system as designed cannot move efficiently (viscosity of MIL-H-6083B at −53.9 C is 4500 cSt).

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Because it is neither economically feasible to modify the large number of tanks to achieve all temperature operation with a single fluid nor logistically sound to depend on two fluids to cover low and high temperature operation, notwithstanding the attendant storage and handling problems, the development of a single hydraulic fluid to permit operation of existing equipment over the wide service temperature range becomes extremely important. Accordingly, this laboratory undertook work (*2*) to develop a hydraulic fluid which would be suitable for the M48A2 or M60 tank at all temperatures.

A preliminary study of the operating characteristics and environmental factors led to the conclusions that the tank hydraulic fluid must not only have suitable viscometric properties to permit optimum performance at all temperatures, but also must provide good rust protection, effective antiwear and oxidation stability, and exhibit minimum foaming and leakage characteristics. In addition, the fluid must be from a petroleum base stock to

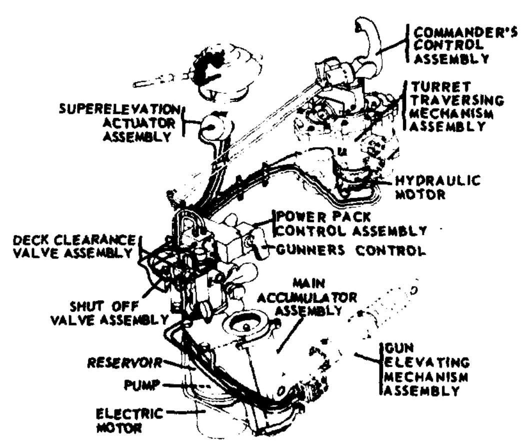

Fig. 1—Gun Elevating and Turret Traversing System.

permit compatibility with seals, packings and "O" rings found in existing military ground equipment.

The work reported here describes the successful development of a hydraulic fluid which permits operation of the M48A2 tank gun control system over the temperature range from −53.9 C to 98.9 C for long periods of time.

EXPERIMENTAL AND TEST RESULTS

Preliminary performance tests showed that after approximately five seconds of operation a presently qualified petroleum fluid meeting MIL-H-6083B (4500 centistokes at −53.9 C, 10 centistokes at 54.4 C) permitted a maximum rotational speed for gun and turret of 215 mils per second at −31.6 C (200 mils per second within 18 seconds was considered acceptable for operation at −53.9 C (*3*)). Since the viscosity of the MIL-H-6083B hydraulic fluid at −31.6 C was found to be 350 centistokes, it was deduced that this value would probably be the viscosity needed for satisfactory operation of the gun control system at −53.9 C. The first approach, therefore, was to obtain a commercially available, relatively low aromatic, petroleum base stock having such viscometric properties. Physical and chemical characteristics of the high aniline point fluid selected are given in Table 1.

Comparative performance tests were then conducted (*3*) with the petroleum base stock and a MIL-H-6083B fluid in an M48A2 tank. It was found (Fig. 2) that from 20 C to 52 C, the performance of the two fluids was nearly the same. As the temperature dropped, however, differences in performance became very pronounced as shown by the fact that at −40 C, the MIL-H-6083B hydraulic fluid permitted a rotational speed of 140 mils per second and the low viscosity fluid 350 mils per second. These speeds were achieved five seconds after the gunner set his control for maximum slew rate. At −53.9 C, the base fluid permitted speeds of 200 mils per second after 15 seconds and 426.7 mils per second after four minutes of operation. In contrast, MIL-H-6083B fluid, after a starting rotational speed of approximately 15 mils per second at −53.9 C permitted the turret to rotate only 300 mils per second after 30 minutes of operation. The original premise that satisfactory operation of the turret at −53.9 C, could be achieved with a fluid having a viscosity of approximately 350 centistokes was borne out by the fact that the base fluid permitted rotational speeds of 200 mils per second after 15 seconds of operation at −53.9 C (the latter is equivalent to the performance of the MIL-H-6083B at −31.6 C).

On the basis of the satisfactory low temperature performance, the base stock was then modified with appropriate anti-wear, oxidation and rust inhibitors to provide the required physical and chemical properties necessary for possible use in all environments. The composition of the blend (designated PD-840) is given in Table 2 and its properties are listed in Table 1.

Since the base fluid used in formulating PD-840 represented a very low viscosity petroleum fraction (1.00 centistoke at 98.9 C, 250 centistokes at −53.9 C), it became necessary to conduct performance tests in M48A2 tanks to determine whether such a low viscosity fluid would perform satisfactorily over long periods of time, particularly with respect to response rates, leakage and wear. Accordingly, the turret and gun hydraulic control system of an M48A2 tank was completely disassembled and examined for compliance with specifications (*4*). Micrometer measurements were made on the pistons and cylinders in the traversing motor (Fig. 3). The latter was selected for very close examination because it is the prime component controlling turret performance. This is because turret velocity is dependent upon the speed attained by the traversing motor when fluid is directed through it, in a manner very similar in principle to a water wheel. It is obvious therefore, that as the driving fluid increases in viscosity, as the ambient temperature decreases, operation of the traversing motor will become sluggish and the turret velocity will decrease. Conversely, as the ambient temperature goes up and the viscosity of the hydraulic fluid decreases, turret velocity will improve to an optimum. Peak performance can be expected thereafter for an indefinite range of temperature increases. Ultimately, however, temperatures and viscosities reach a point where leakage, loss of precision control and the possibility of excessive wear of moving parts may be expected (*5*).

The hydraulic system was then reassembled using new BUNA N "O" rings, gaskets and seals and the turret was placed on a supporting stand. Due to space limitations of the environmental test chamber, the gun tube was

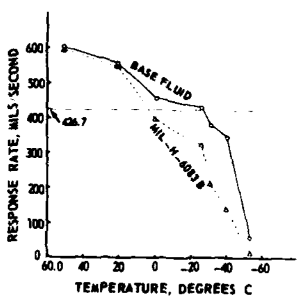

Fig. 2—Power Acceleration, MILS/SEC. Versus Temperature (Elapsed Time 5 Seconds).

Fig. 3—Traversing Motor—Pistons and Cylinders.

Table 1. PROPERTIES OF BASE FLUID AND PD-840

	Test Method	Base Fluid	PD-840
Viscosity, Centistokes	ASTM D 445		
[illegible] C		1.0	1.32
[illegible] C		2.0	3.30
[illegible] C		70.0	74.30
[illegible] C		250.0	381.00
Flash Point, C	ASTM D 92	93.3	104.4
Fire Point, C	ASTM D 92	104.4	107.2
Pour Point, C	ASTM D 97	−59.4	below −56.7
Low Temperature Stability [illegible] C, 72 hours	Fed. Std. Test Method 3459	No separation or precipitation	No separation or precipitation
Neut. No.	Fed. Std. Test Method 5106	0.10	0.09
Carbon Residue	ASTM D 524	0.05	0.03
Aniline Point	ASTM D 611	150 min.	156.6
Oxidation-Corrosion Stability [illegible] C, 168 hours	Fed. Std. Test Method 5308	Inhibited with 0.5% wt. di-tert-butyl-p-cresol	Inhibited with 0.5% wt. phenyl-1-naphthylamine
Wt. Loss			
Mg mg/sq. cm		±0.20	0.09
Ag mg/sq. cm		±0.20	0.04
Steel mg/sq. cm		±0.20	0.07[a]
Al mg/sq. cm		±0.20	0.13
Cu mg/sq. cm		±0.60	0.21
Vis. Change at 37.8 C, %		−5 to +15	+9.8
Insol., g/100 ml		0.001	—
Rubber Swell, % L stock at 70 C for 168 hrs	Fed. Std. Test Method 3603	15 to 28	25
Clay-Gel Analysis, Wt., %	ASTM D 2007		
Asphaltenes		0.5	—
Polar		2.0	—
Aromatics		25.0	—
Saturates		70.0	—
Galvanic Corrosion	Fed. Std. Test Method 5322-T	Pass	Pass
Anti-Wear	Fed. Std. Test Method 6514		
Scar dia., mm[b]			
10 kg		0.787	0.337
40 kg		0.846	0.758
Foam	ASTM D 892		
23.9 C		—	Complete collapse within 30 seconds
93.3 C		—	Complete collapse within 10 seconds
Rust Protection[c]	Cyclic Humidity Cabinet	<24 hours	216 hours

[a] Cadmium plated steel
[b] Four Ball Tester, +75 C, 1200 rpm for one hour
[c] Determined in the Frankford Arsenal cyclic humidity cabinet, in which 1020 steel cylindrical rods 3/8" × 4" were coated with the test oils and exposed to alternating cycles of 4 hours at 43.3 C and 80% RH followed by 4 hours at 54.4 C and 95% RH.

removed and weights substituted so that the center of gravity of the turret remained the same (Fig. 4). These modifications in no way altered the performance characteristics of the gun and turret which is independent of the vehicle body. The test unit was allowed to soak overnight at an ambient temperature of 51.7 C in the climatic chamber. The gunner's control was then set to rotate the turret at 50 mils per second which quickly

Table 2—COMPOSITION OF PD-840 FLUID

Composition	Wt., %
Base oil	95.0
Tricresyl phosphate	1.5
Phenyl-1-naphthylamine	0.5
Barium dinonylnaphthylene sulfonate	3.0

brought the bulk fluid temperature up to an average of 98.9 C. At the end of each day (i.e., eight hours) an external examination was made of the hydraulic system for leaks. None was reported over the life of the test which was terminated after 213 hours. During the performance test, maximum turret velocities (slew rates) were determined for different input angles of the gunner's control. Data obtained throughout and at the conclusion of 213 hours of testing (Fig. 5) showed that at all settings except the maximum, response rates equaled or exceeded suggested performance requirements (*6*). Samples of oil were removed at intervals during the performance test for examination. The data on these samples are given in Table 3.

At the conclusion of the test, the hydraulic system was disassembled and measurements made on the pistons and cylinders of the traversing motor (Fig. 3). The data (Table 4) show that the diametrical clearances (difference between piston diameter and cylinder diameter) at the start of the test averaged 0.0012 inch; after 213 hours, clearances averaged 0.0014 inch. Field test data have shown that a diametrical clearance of 0.003 inch (*7*) would still permit satisfactory operation of the gun and turret. The components, therefore, were not only in excellent condition but in fact could have been used once again for additional performance tests.

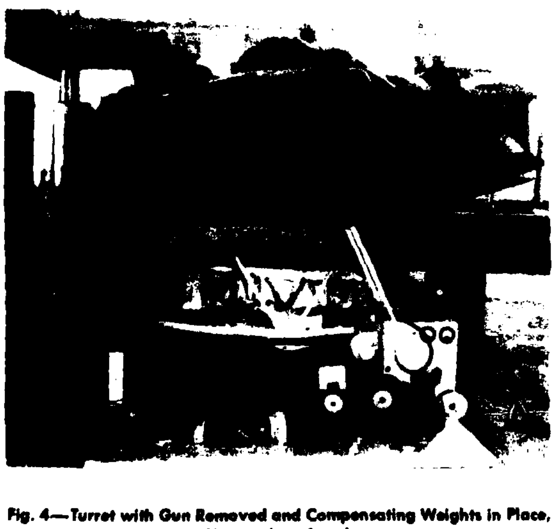

Fig. 4—Turret with Gun Removed and Compensating Weights in Place, Mounted on Stand.

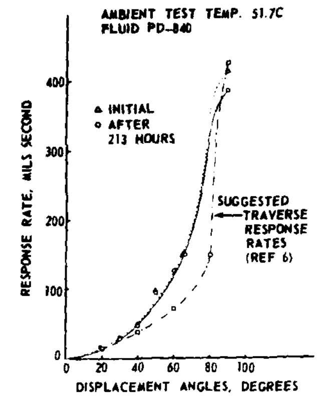

Fig. 5—Turret Traversing Rate Versus Input Angle.

DISCUSSION

Since the viscosity of the PD-840 blend, dictated by low temperature performance requirements, is significantly below that of currently used fluids conforming to MIL-H-6083B specification, predicting long term operational behavior was somewhat questionable. However, there was reason to believe that hydraulic system performance would be satisfactory despite the fact that there was no prior tank experience where fluids so low in viscosity had been used. This was reasoned from data in reports covering the development and evaluation of high temperature fluids (*8*, *9*, *10*, *11*). A case in point is the study of MLO-60-294. The fluid, a deep-dewaxed, highly refined paraffinic base stock contained one percent tricresyl phosphate, one percent of a hindered bis phenol and one-thousandth of one percent of a silicone defoamer. Evaluating MLO-60-294 in hydraulic fluid test stands utilizing aircraft components, Hopkins (*9*) and Benzing (*10*) reported excellent performance characteristics at 287.8 C notwithstanding that the viscosity of the fluid at this temperature was 0.65 centistoke. Although the results were not necessarily extrapolatable to the tank gun control system due to differences in hardware, operating pressures, etc., it was reassuring to learn that pump performance was satisfactory and that a low viscosity fluid suitably inhibited permitted only minimal wear.

Table 3—PROPERTIES OF PD-840 DURING HIGH TEMPERATURE TEST

Running, Hours	Viscosity, (cSt) 37.78 C	Viscosity, (cSt) −53.9 C	Neut. No.	Rust Protection, Hours[a]
0	3.30	381	0.09	216
34	3.48	410		
43	3.47	407		
213	3.47	401	0.09	216

[a]Same as "c" in Table 1.

TABLE 4 MEASUREMENTS (INCH) OF HYDRAULIC MOTOR PISTONS AND CYLINDERS BEFORE AND AFTER 213 HOURS OF TESTING

	Initial			Final			Piston Length	
Cylinder Number	Cylinder Diameter	Piston Diameter	Clearance	Cylinder Diameter	Piston Diameter	Clearance	Initial	Final
1	.4079	.4069	.0010	.4080	.4069	.0011	.9955	.9955
2	.4077	.4065	.0012	.4077	.4065	.0012	.9955	.9955
3	.4073	.4067	.0006	.4073	.4067	.0006	.9965	.9965
4	.4086	.4074	.0012	.4086	.4073	.0013	.9960	.9959
5	.4084	.4069	.0015	.4084	.4069	.0015	.9956	.9952
6	.4125	.4109	.0016	.4127	.4109	.0018	.9927	.9927
7	.4120	.4110	.0010	.4124	.4110	.0014	.9953	.9953
8	.4125	.4114	.0011	.4127	.4113	.0014	.9952	.9951
9	.4127	.4114	.0013	.4129	.4113	.0016	.9971	.9971
10	.4080	.4068	.0012	.4080	.4067	.0013	.9968	.9968
11	.4125	.4109	.0016	.4129	.4109	.0020	.9918	.9918
12	.4125	.4110	.0015	.4126	.4110	.0016	.9955	.9955
13	.4080	.4071	.0009	.4082	.4070	.0012	.9964	.9964
14	.4075	.4064	.0011	.4076	.4064	.0012	.9949	.9949
Average	.4099	.4087	.0012	.4100	.4086	.0014	.9953	.9953

Within the M48A2 hydraulic system as in many other fluid lubricated systems, there exists two fundamental types of lubrication; namely, hydrodynamic or "thick film" and boundary or "thin film". Under ideal hydrodynamic conditions of lubrication, i.e., the laws of hydrodynamics are valid on fluid films thicker than 0.000025 inch (*12*) (clearances between pistons and cylinders in the traversing motor of the M48A2 tank average 0.0012 inch (Table 4)), there should be no abrasive wear since the moving parts theoretically never touch each other. If, however, the fluid film which separates the metal surfaces decreases in thickness due to a change either in viscosity or work load, it is highly probable that hydrodynamic lubrication would be replaced by boundary lubrication (metal-to-metal contact). At bulk fluid temperatures of approximately 98.9 C encountered in the tank performance test, the viscosity of PD-840 was 1.32 centistokes. In essence, this meant that the flow capability of the fluid had increased over normal room temperature levels, and was consequently more easily displaced. It was quite possible, therefore, that many of the gun control hydraulic components having extremely small diametrical clearances would have progressed from hydrodynamic to boundary conditions with the increase in temperature and load. In the area of boundary lubrication, viscosity becomes much less important and it is the chemical properties of the fluids or additives which determine lubricating capability.

The literature is repleat with references which show tricresyl phosphate (TCP) to be an effective anti-wear additive in petroleum lubricants which are used in systems fabricated largely of steel. Godfrey (*13*), Klaus (*14*), Bieber (*15*), Barcroft (*16*), and Rounds (*17*) have shown that when steel sliding on steel was lubricated with TCP, the phosphoric acid in or formed by TCP reacted with the steel surfaces to form a protective iron phosphate coating which reduced wear. In the work reported here, the 213 hour test period represented an approximate maximum operational use time of the tank before overhaul. In view of the fact that the gun control system is used infrequently in field operation, 213 hours of continuous cycling of gun and turret represented operational time far beyond that normally specified for overhaul. It is especially significant, therefore, that performance which is dependent upon tolerances of hydraulic components remained excellent throughout this period. Examination of the disassembled traversing motor parts indicated that clearances between pistons and cylinders increased an average of only 0.0002 inch (Table 4) which was not enough to affect response rates. This gave proof of the efficacy of TCP (containing polar impurities) in the system.

SUMMARY

A hydraulic fluid has been developed which permits effective operation of the U. S. Army's M48A2 and M60 battle tanks over the temperature range from −53.9 C to 98.9 C. Immediate economies realized through the use of this fluid are the elimination of the need for:

1. Several fluids of different viscosities to cover the desired operating temperature range.
2. Hardware modification and retrofit of existing tanks.
3. Installation of auxiliary heating equipment.

The latter two would be necessary in order to permit the use of presently specified MIL-H-6083B hydraulic fluids at −53.9 C.

The work described here provides evidence of an important technological advancement to the military services since it has been demonstrated that a suitably inhibited low viscosity hydraulic fluid is useful in ground systems over a wide range from −53.9 C to 98.9 C for long periods of time.

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13. ABSTRACT

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hydraulic fluid						
Petroleum base hydraulic fluid						
Low viscosity hydraulic fluid						
Tank systems lubricant						
Rust inhibited hydraulic fluid						
All season hydraulic fluid						
Low temperature hydraulic fluid						
Stable hydraulic fluid						
Lubricants						
Hydraulic fluid for ground equipment						